



An Investigation on the Pozzolanic Reactivity of Different Materials and Their Effects on the Properties of Ultra-high Performance Concrete (UHPC)

A. Pourjhanshahi, H. Madani*

Civil engineering faculty, Graduate University of Advanced Technology, Kerman, Iran

ABSTRACT: The partial replacement of cement with industrial wastes, especially in the concretes with high volume of cement-based materials such as ultra-high performance concretes (UHPC) may have positive effects on the environment and could lead to improvements in concrete properties. However, the effects of some types of these materials, such as coal waste and copper slag, have not been investigated seriously. In this study, the effects of several cement-based materials with different pozzolanic reactivity from very active (like silica fume) to approximately inactive (like silica powder) have been studied on the UHPC properties. Since the treatment temperature of 70-100 °C intensifies the possibility of delayed ettringite formation, thermal curing at 60 °C and 90 °C have been selected as the treatment temperatures of low and high risk of delayed ettringite formation, furthermore the results have been compared with the standard thermal curing at 20 °C. An electrical conductivity method has been used to compare the pozzolanic reaction rate of materials. In this study, compressive strengths, modulus of rupture and rapid chloride migration coefficients have been determined and the investigation of microstructure has been carried out using scanning electron microscopy. The obtained results show that use of heat treatment for the mixtures incorporating materials with low pozzolanic reactivity may reduce the strength and durability of ultra-high performance mixtures. The differences between the results obtained from the thermal curing conditions of 60 °C and 90 °C were not significant, however use of thermal curing at 90 °C requires higher energy demand compared with the thermal curing at 60 °C, moreover higher risk of delayed ettringite formation is expected.

Review History:

Received: 24 May 2017

Revised: 1 July 2017

Accepted: 23 October 2017

Available Online: 29 October 2017

Keywords:

Pozzolanic Activity

Mechanical Properties

Durability

Cement Replacement Materials

Thermal Curing

Ultra-high Performance Concrete

1- Introduction

The high level of waste production in the industrial processes as well as releasing pollutant gases, such as carbon dioxide in the cement production, has destructive effects on the environment and the quality of human life. One of the challenges of the recent decades is the production of concrete with lower clinker content but with similar mechanical and durability properties [1]. Numerous studies have been conducted with the aim of using wastes as cement replacement materials [2]. Different strategies such as reducing the water to cement ratio, thermal curing and use of mineral admixtures have been proposed to improve the properties of ultra-high performance concrete [3, 4]. Among them, use of mineral admixtures appears to be the most effective and economical method owing to reducing the amount of cement consumption [5]. In this research, the effects of several cement-based materials with different pozzolanic activities on the properties of ultra-high performance concrete have been investigated. For this purpose, silica fume, glass powder, copper slag, coal waste and silica powder were replaced at 10% of cement.

Duration and temperature of curing conditions may have many positive effects on the pozzolanic reactivity of materials. To have better understanding about the behavior of

the mentioned materials on the concrete properties, standard curing at 20 °C and thermal curing at 60 °C and 90 °C have been conducted. In addition, the tests have been carried out at the ages of 3 to 120 days in order to determine the effect of time on the pozzolanic reactivity of materials and UHPC properties.

In this study, initially, the pozzolanic reactivity of materials has been investigated by an electrical conductivity method. Then, the performance of these materials on the mechanical properties, durability and microstructure have been studied utilizing compressive strength, modulus of rupture, rapid chloride migration and the scanning electron microscope (SEM) measurements.

2- Results

2- 1- Pozzolanic Reactivity of Materials

In order to determine the reaction rates with calcium hydroxide, this experiment was carried out according to previous researches [6, 7]. In this method, when the alkalinity amount of pore solution increases, the dissolution rate of materials rapidly raises. As the glass powder is the most alkaline material, the dissolution rate of it increases, due to an endothermic process. Silica fume, silica powder and copper slag are almost inactive but the acidity of coal waste may negatively affects the concrete properties. According to the obtained results of the pozzolanic reactivity test, it can be

Corresponding author, E-mail: h.madani@kgut.ac.ir

concluded that glass powder, silica fume and coal waste have the highest pozzolanic properties, respectively. Silica powder and copper slag did not show high potential for reaction with calcium hydroxide. As a result, it can be mentioned that amorphous condition, pH and particle dimension of a material have great effects on the reactivity with calcium hydroxide.

2- 2- Compressive Strength

Use of different waste materials, such as glass powder, copper slag, and silica powder leads to significant reduction of the compressive strengths at the early age, however, by increasing the age up to 120 days, their results were not significantly different with the plain mixture. The use of silica fume increased compressive strength after 7 days but coal waste reduced compressive strength at all ages. On the other hand, thermal curing increased significantly the compressive strength at early ages, and this affect decreased over the time.

2- 3- Modulus of Rupture

Among the materials, use of coal waste reduced the modules of rupture at the age of 28 days but the replacement of other materials increased it. At the age of 120 days and standard curing condition, the modulus of rupture of specimens, were comparable with the plain mixture. However, increasing the temperature to 60 and 90 °C led to lower modulus of rupture. Silica fume incorporated mixtures had different trends and higher values compared with the plain mixture were obtained. It can be deduced that thermal curing may increase the pozzolanic activity of silica fume and could not have positive effect on the other materials.

2- 4- Rapid Chloride Migration Coefficients

The results indicate that, among the mineral supplementary cementitious materials, silica fume had the best performance, during the all types of curing methods, so that its chloride coefficient in the standard, thermal 60 °C and thermal 90°Curing conditions decreased by about 87, 85 and 93% in comparison with the plain mixture, respectively. The 10% replacement of cement with the other materials including glass powder, silica powder, copper slag and coal waste resulted in higher migration coefficients in the rapid chloride migration test in the all type of curing at the age of 28 days. It means that use of these materials has destructive effects on the durability. It is expected that these materials (other than silica fume) had pozzolanic reactions at the later ages, hence they have not positive effects on the durability of concrete at the age of 28 days. At the age of 120 days, the obtained results of thermal curing at 60 °C have shown negligible changes in comparison with the standard curing (except for silica fume mixture) and thermal curing at 90 °C had many negative effects on the concrete durability.

2- 5- Scanning Electron Microscopy (SEM)

According to the results, coal waste and silica fume had the worst and best performance on the ultra-high performance concrete properties, respectively, therefore the scanning electron microscopy images of silica fume and coal waste concrete samples have been investigated. Coal waste had not a positive effect on microstructure so that Portlandite crystals could be observed (Figure 1A and B).

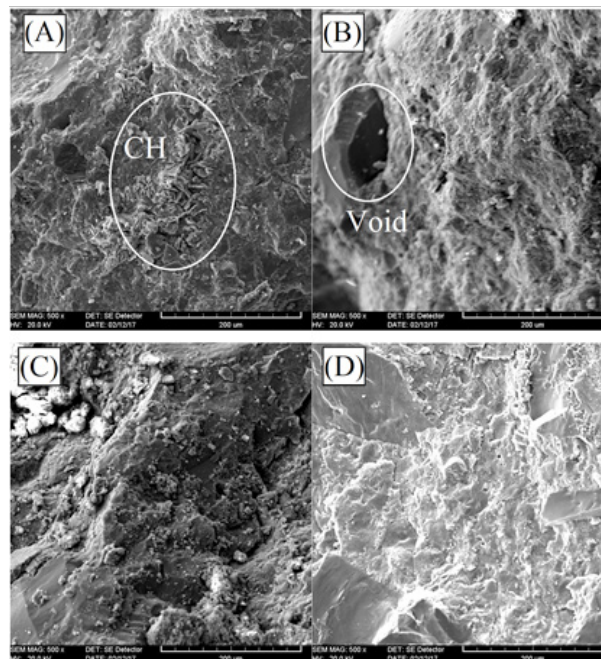


Figure 1. Scanning electron microscopy images of A) Coal waste mixture under standard curing. B) Coal waste mixture under thermal curing at 90°. C) Silica fume mixture under standard curing. D) Silica fume mixture under thermal curing at 90°.

In the coal waste mixture, the interfacial transition zone between the cement paste and the aggregate is so weak and a separation between aggregate and paste could be noticed. On the other hand, silica fume had a significant effect on the microstructure density, and there is no sign of Portlandite and ettringite crystals. Thermal curing at 90 °C had a great effect on the microstructure of silica fume mixture, but it weakened the interfacial transition zone in the coal waste mixture.

References

- [1] P.R. Rangaraju, J. Olek, S. Diamond, An investigation into the influence of inter-aggregate spacing and the extent of the ITZ on properties of Portland cement concretes, *Cement and Concrete Research*, 40(11) (2010) 1601-1608.
- [2] W.A. Moura, J.P. Gonçalves, M.B.L. Lima, Copper slag waste as a supplementary cementing material to concrete, *Journal of Materials Science*, 42(7) (2007) 2226.
- [3] X.H. Wang, S. Jacobsen, S.F. Lee, J.Y. He, Z.L. Zhang, Effect of silica fume, steel fiber and ITZ on the strength and fracture behavior of mortar, *Materials and structures*, 43(1-2) (2010) 125.
- [4] P.K. Mehta, *Concrete. Structure, properties and materials*, (1986).
- [5] Z. Wu, C. Shi, K. Khayat, Influence of silica fume content on microstructure development and bond to steel fiber in ultra-high strength cement-based materials (UHSC), *Cement and Concrete Composites*, 71 (2016) 97-109.

[6] M.d. Luxán, F. Madruga, J. Saavedra, Rapid evaluation of pozzolanic activity of natural products by conductivity measurement, *Cement and concrete research*, 19(1) (1989) 63-68.

[7] J. Paya, M. Borrachero, J. Monzo, E. Peris-Mora, F. Amahjour, Enhanced conductivity measurement techniques for evaluation of fly ash pozzolanic activity, *Cement and Concrete Research*, 31(1) (2001) 41-49.

Please cite this article using:

A. Pourjhanshahi, H. Madani, An investigation on the pozzolanic reactivity of different materials and their effects on the properties of ultra-high performance concrete (UHPC), *Amirkabir J. Civil Eng.*, 50(4) (2018) 707-724.
DOI: 10.22060/ceej.2017.12909.5291



